Pharmaciana
Vol.9, No.1, May 2019, Page. 29-40
ISSN: 2088 4559; e-ISSN: 2477 0256
DOI: 10.12928/pharmaciana.v9i1.11892

Esterification of *p*-hydroxybenzoic acid with glucose using a γ-Al_2O_3/SO_4 catalyst

Elfia Siska Yasa Putri[*1], Widajanti Wibowo[2], Soleh Kosela[2]
[1]Faculty of Pharmacy and Sciences, Universitas Muhammadiyah Prof. Dr. Hamka
Islamic Center Delima Raya II/IV Street, Perumnas Klender, Jakarta Timur
[2]Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok
Universitas Indonesia, Kampus UI, Depok

Submitted: 24-11-2018 ***Reviewed: 26-11-2018*** ***Accepted: 20-04-2019***

ABSTRACT

Esterification of p-hydroxybenzoic acid with glucose can be expected to produce esters. The rate of esterification reaction is usually very slow and, therefore, needs an acid catalyst to accelerate it. This research examined the performance of a heterogeneous catalyst made of γ-Al_2O_3 impregnated with a protic acid, H_2SO_4. The heterogeneous catalyst, γ-Al_2O_3/SO_4, was characterized using FTIR, XRD, XRF, and BET methods. The esterification reactions were conducted using dimethyl sulfoxide (DMSO) solvent at a temperature of 100^0C and observed after they lasted for 1 to 24 hours (reaction time). The esterification of p-hydroxybenzoic acid with glucose used two catalysts, namely 3% SO_4^{2-}/Al_2O_3 and 5% SO_4^{2-}/Al_2O_3. The reaction products were analyzed using FTIR, HPLC, nd LC-MS methods. The % yield was the highest at Hour 24 for both catalysts, while the % conversion fluctuated during the esterification time. The LC-MS showed that the three produced esters had molecular weights of 300, 420, and 540.

.

Keywords: esterification, p-hydroxybenzoic acid, glucose, SO_4^{2-}/Al_2O_3 catalyst

Corresponding author:
Elfia Siska Yasa Putri
Universitas Muhammadiyah Prof. DR. Hamka
Islamic Center, Delima Raya II/IV Street, Perumnas Klender, Jakarta Timur
Email: elfia.siska@uhamka.ac.id

INTRODUCTION

Esterification is one of the most important reactions used in industries such as perfume, pharmaceuticals, food and beverage, and biodiesel. The most common method for processing esters is by heating a carboxylic acid (R-COOH) with alcohol (R-OH) while removing the water generated by the reaction. The mechanism of Fischer esterification is presented in Figure 1.

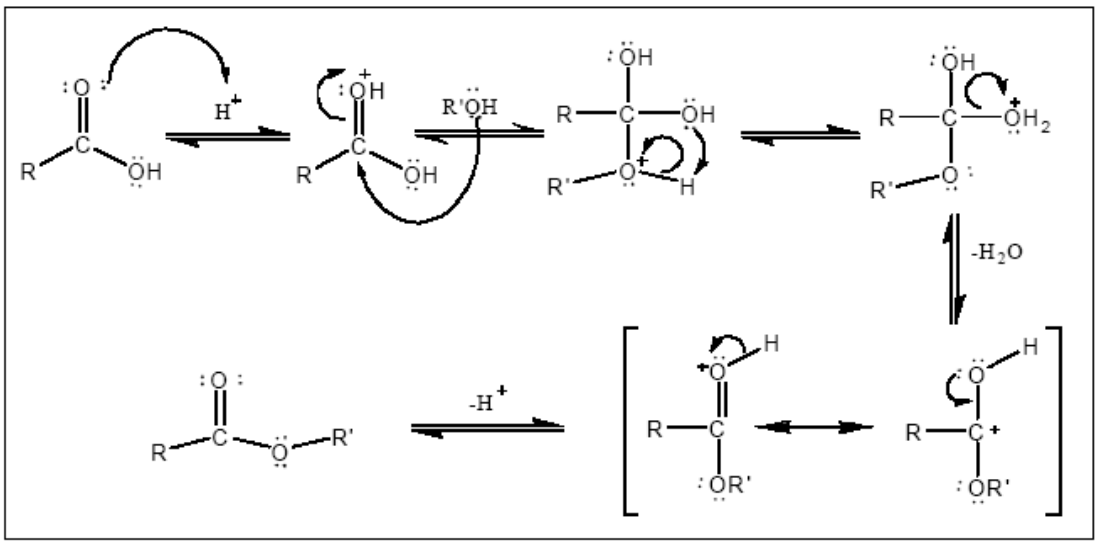

Figure 1. Mechanism of Fischer esterification (Fessenden and Fessenden, 1989)

Esterification is slow and, therefore, a catalyst is needed to speed up the reaction. Moreover, catalysts, including the heterogeneous ones, can achieve reasonable conversion rates. Several studies have examined the use of heterogeneous acid catalysts (Lo *et al.*, 2008) and suggested that esterification in zirconium tungstate (ZW) occurs between acetic acid and methanol from the liquid phase to the gas phase. Also, the mechanism of esterification between acetic acid and short-chain alcohol (methanol and ethanol) used silica-supported Nafion (SAC-13) as the catalyst (Suwannakarn, Lotero, and Goodwin, 2007). Furthermore, Su *et al.* (2009) have synthesized methyl salicylate from salicylic acid and dimethyl carbonate using mesoporous aluminosilicate.

One of the frequently used heterogeneous acid catalysts is γ-alumina. γ-alumina has several advantages, including maintained stability at high temperatures and varying pores structure. Also, it can be modified by impregnation and co-precipitation to increase its catalytic activity. Sulfated aluminas are made via the sol-gel method in the esterification of oleic acid with ethanol. During esterification, it exhibits higher catalytic activity than un-sulfated aluminas (Alvarez *et al.*, 2009). Furthermore, Yb_2O_3-Al_2O_3 supported SO_4^{2-}/ZrO_2 catalyst has also been proven to create optimal esterification because the acid sites of the catalyst are elevated (Yu *et al.*, 2009). In the esterification of free fatty acid in crude palm oil, SO_4^{2-}/Al_2O_3-SnO_2 catalyst has very high acidity and, therefore, can be used to produce methyl esters (Prasitturattanachai and Nuithitikul, 2013). The total acidity of Cu-Ni(3:1)/γ-Al_2O_3 is estimated at 2.3 mmol/g, whereas the total acidity of γ-Al_2O_3 is 1.6 mmol NH_3/g (Pudi *et al.*, 2014).

The sulfation of γ-Al_2O_3 influences its catalytic activity, product selectivity, and glycerol conversion (Rane, 2016), and it significantly increases the acid strength because of the inductive effect on the S=O bond (Alvarez *et al.*, 2009). The structure of SO_4^{2-}/Al_2O_3 is presented in Figure 2.

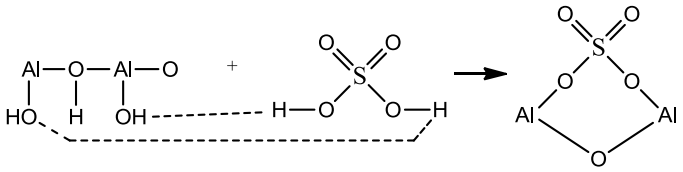

Figure 2. Structure of SO_4^{2-}/Al_2O_3 (Alvarez *et al.*, 2009)

Therefore, this research proposed to perform esterification of p-hydroxybenzoate with glucose using 3% gram/mmol SO_4^{2-}/Al_2O_3 catalyst and 5 % gram/mmol SO_4^{2-}/ Al_2O_3 catalyst. The activity of the catalyst was gained through the conversion of reactant into esters. The esterification of p-hydroxybenzoic acid with glucose can be used as a preservative in the food industry. The produced esters can maintain the quality of food products.

MATERIALS AND METHOD

Materials

Aluminum scrap, demineralized water (Aqua Demine), NH_4OH 25%, 1 N H_2SO_4, CH_3COONH_4 4%, $NaHCO_3$, glucose, p-hydroxybenzoic acid, DMSO, ethyl acetate, and methanol.

Method

Synthesis of SO_4^{2-}/Al_2O_3 catalyst

The first step was dissolving aluminum scrap in H_2SO_4 thoroughly by heating. After filtration, 50 mL of this solution was mixed with 50 mL of demineralized water and titrated with NH_4OH 25% until the pH reached 8-9 (Prasitturattanachai and Nuithitikul, 2013). The formed solution was subjected to hydro-thermalization in a propylene bottle at a temperature of 80-90^{0}C for 96 hours, washed with demineralized water until it was neutral and free of sulfate, and heated in the oven at 140°C for 16 hours until boehmite was formed. The dried boehmite was added with 15 mL of 1N H_2SO_4 for every gram of catalyst and then subjected to decantation and re-drying at 140^{0}C for 16 hours. Afterward, the dried suspension was calcinated at 650^{0}C for 4 hours (Kiss *et al*., 2008).

The formed catalyst was characterized with X-ray Diffraction (XRD), X-ray fluorescence (XRF), BET and and Fourier-Transform Infrared Spectroscopy (FTIR). To determine the crystal structure of the catalyst, the XRD was performed in a PW 1710 diffractometer with Cu-Kα (λ=0.154 nm) radiation set at 40 kV. The data was obtained from the 2θ range between 10^0 and 80^0 with a step of 0.02^0/s. The XRF analysis was applied to identify the constituent elements of the catalyst and, therefore, was set at 30 kV and 0.120 mA with a live time of 110 sec. Also, the Brunauer–Emmett–Teller (BET) method was used to measure the specific surface area, cumulative pore volumes, and average pore diameters of the catalyst. It was conducted at the N_2 adsorption/desorption isotherm, i.e., 77.350 K, in Quantachrome v.2.1.

Esterification of p-hydroxybenzoic acid and glucose

The esterification was performed with 10 mL of dimethyl sulfoxide (DMSO) as the solvent at 100^{0}C for 1, 2, 3, 4, 6, 8, 12, 18, and 24 hours. It blended 0.138 gram of p-hydroxybenzoic acid and 0.54 gram of glucose with 3% gram/mmol catalyst and 5 % gram/mmol catalyst. This analysis used both FTIR and Liquid Chromatography-Mass Spectrometry (LC-MS). The FTIR analysis of ester was performed with KBr pellets and a Shimadzu spectrometer, which was run at room temperature, wavenumbers ranging from 650 to 4000 cm^{-1}, and atmospheric condition. Performed in a Mariner Biospectrometry Workstation, the LC-MS analysis produced ester after 24-hour esterification with 3% gram/mmol catalyst. The LC used Hitachi L6200 and an injection of 20 µL, and the results were obtained from the Supelco C_{18} column (150 mm x 2 mm). The mobile phase consisted of solvent A (methanol) and solvent B (water). The samples were eluted isocratically at a flow rate of 1 mL/min and Electrospray Ionisation (ESI) system; the ratio of methanol to water volume was 80:20.

Esterification with High-Pressure Liquid Chromatography (HPLC)

The esterification of p-hydroxybenzoic acid with glucose was carried out at 100^0C for 1, 2, 3, 4, 6, 8, 12, 18, and 24 hours. Esters were analyzed every 2.5 minutes using HPLC (Shimadzu) equipped with an octadecylsilyl (ODS) column, and UV Photometer and Detector. The mobile phase was methanol and Aqua Bidest, whereas the stationary phase was C_{18} octadecane with gradient elution system.

Data Analysis

The conversion of p-hydroxybenzoic acid, as analyzed with HPLC, was defined with the following formula (Miranda *et al.*, 2014):

$$\text{Conversion of p-hydroxybenzoic acid (\%)} = \frac{\text{Moles of p} - \text{hydroxy benzoic acid reacted}}{\text{Initial moles moles of p} - \text{hydroxy benzoic acid}} \times 100$$

The yield of the product was measured with HPLC and calculated using the following equation (Ramli and Farooq, 2015):

$$\text{The yield of ester (\%)} = \frac{\text{Weight of ester}}{\text{Weight of p} - \text{hydroxy benzoic acid}} \times 100$$

RESULTS AND DISCUSSION

Catalyst Synthesis

The production of the catalyst involved many steps. The initial stage was the amalgamation of smooth aluminum scrap and H_2SO_4. Next, this solution was heated up using a hot plate.

$$2Al + 6\ H_2SO_4 \rightarrow Al_2\ (SO_4)_3 + 3SO_2 + 6H_2O$$

Then, the ammonium hydroxide solution was added to the reaction to maintain the acidity (pH) at 8-9 and finally produce boehmite. This reaction is as follows:

$$Al_2(SO_4)_3 + 6\ NH_4OH \rightarrow 2Al\ (OH)_3 + 3\ (NH_4)_2SO_2$$

Afterward, the solution was subjected to hydro-thermalization in a propylene bottle at 80^0C for 96 hours to create a more crystalline boehmite. The sediment was suspended in CH_3COONH_4 4 %, meaning that the deposits obtained from this process are not easily dissolved in a strongly acidic or basic solution. The next stage was the removal of water contained in aluminum hydroxide according to the reaction below:

$$Al(OH)_3 \rightarrow AlO(OH) + H_2O$$

Furthermore, sulfuric acid was added to these deposits to enhance the acid site of the alumina. The solids were dried at 140^0C for 16 hours to form boehmite solids that bound with sulfuric acid. Afterward, they were calcined at 650^0C to create γ-Al_2O_3 that had a large surface area, large pore volume, and stable at a various range of temperature during a catalytic reaction. Kiss *et al*, (2008) have confirmed that 600-700^0C was the optimum temperature range for calcination to considerably influence the activity of a catalyst.

Catalyst Characterization (XRD, XRF, BET, FTIR)

The XRD patterns of boehmite and SO_4^{2-}/Al_2O_3 catalyst are shown in Figure 3.

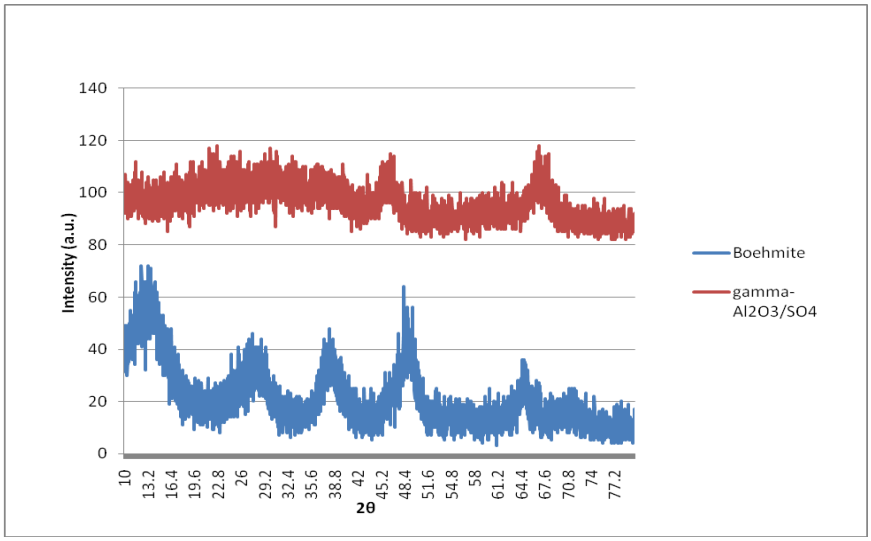

Figure 3. XRD patterns of boehmite and SO_4^{2-}/Al_2O_3

Table I. The diffraction angle (2θ) of synthesized boehmite and standard boehmite (the Hanawalt's table)

Standard boehmite		Synthesized boehmite	
2θ	Relative intensities (%)	2θ	Relative intensities (%)
14.492	100	13.512	94.74
28.213	83	27.907	64.91
38.361	83	38.170	81.14
48.940	69	48.964	100.00
55.260	34	56.827	13.6
64.140	32	64.66	42.98

Table II. The diffraction angle (2θ) of synthesized SO_4^{2-}/Al_2O_3 catalyst and standard SO_4^{2-}/Al_2O_3 catalyst

Standard SO_4^{2-}/Al_2O_3		Synthesized SO_4^{2-}/Al_2O_3	
2θ	Relative intensities (%)	2θ	Relative intensities (%)
45.862	100	45.9397	73.81
67.032	100	67.0627	100

For boehmite (Table I), the presence of several diffraction peaks corresponded to the Hanawalt's table. However, the XRD patterns of boehmite showed six peaks that compared to the Hanawalt's table. The diffraction peak intensities indicated that the synthesized boehmite matched with the standard boehmite. The XRD patterns of SO_4^{2-}/Al_2O_3 catalyst (Table II) showed two peaks, i.e., at 2θ = 45.9397 and 67.0627—in accordance with the Hanawalt's table, and at 2θ = 45.862 and 67.032.

Meanwhile, the diffraction peak intensities of SO_4^{2-}/Al_2O_3 catalyst represented a typical diffraction angle of γ- Al_2O_3. The results of the X-ray Fluorescence (XRF) analysis of solid SO_4^{2-}/Al_2O_3 catalyst are shown in Table III.

Table III. X-ray Fluorescence (XRF) of SO_4^{2-}/Al_2O_3 catalyst

Elements	wt (%)
Al	67.0410
Si	1.2518
S	25.7236
V	0.1162
Fe	4.6380
Ni	0.1272
Cu	0.1218
Zn	0.9293

The Al and S contents of the SO_4^{2-}/Al_2O_3 catalyst were 67.0410 % and 25.7236 %, respectively (Table III). S may enhance the activity of the Lewis acid. The other elements were present at small proportions because the washing in the synthesis of aluminum hydroxide was not perfect. The BET analysis of solid SO_4^{2-}/Al_2O_3 catalyst was performed, and the results showed that the catalyst had a surface area of 223.81 m^2/g. This area is categorized as high because it is within the range of 200 m^2/g-500 m^2/g. The surface area of the catalyst was relatively large because it was between 200 m^2/g and 500 m^2/g. Further observation found that the pore volume was 0.2196 cc/g with an average pore diameter of 3.92525 nm, which fell into the category 'medium pore' (2-50 nm) (Zhang *et al*., 2011). The SO_4^{2-}/Al_2O_3 catalyst was also subjected to FTIR analysis. The results showed a wavenumber of 1194.92 cm^{-1} (Figure 4), which was within the wavenumber region of sulfate groups (1200-1100 cm^{-1}) (Sastrohamidjojo, 2013). In other words, the SO_4^{2-}/Al_2O_3 catalyst indeed contained sulfate ion.

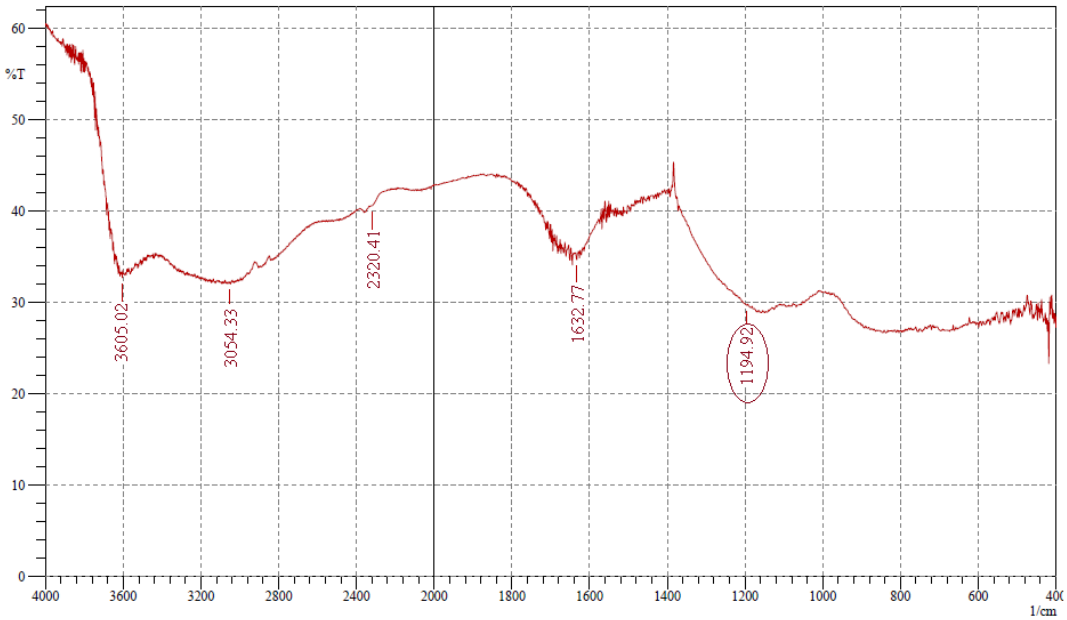

Figure 4. The FTIR graph of the SO_4^{2-}/Al_2O_3 catalyst

Esterification of p-hydroxybenzoic acid with glucose

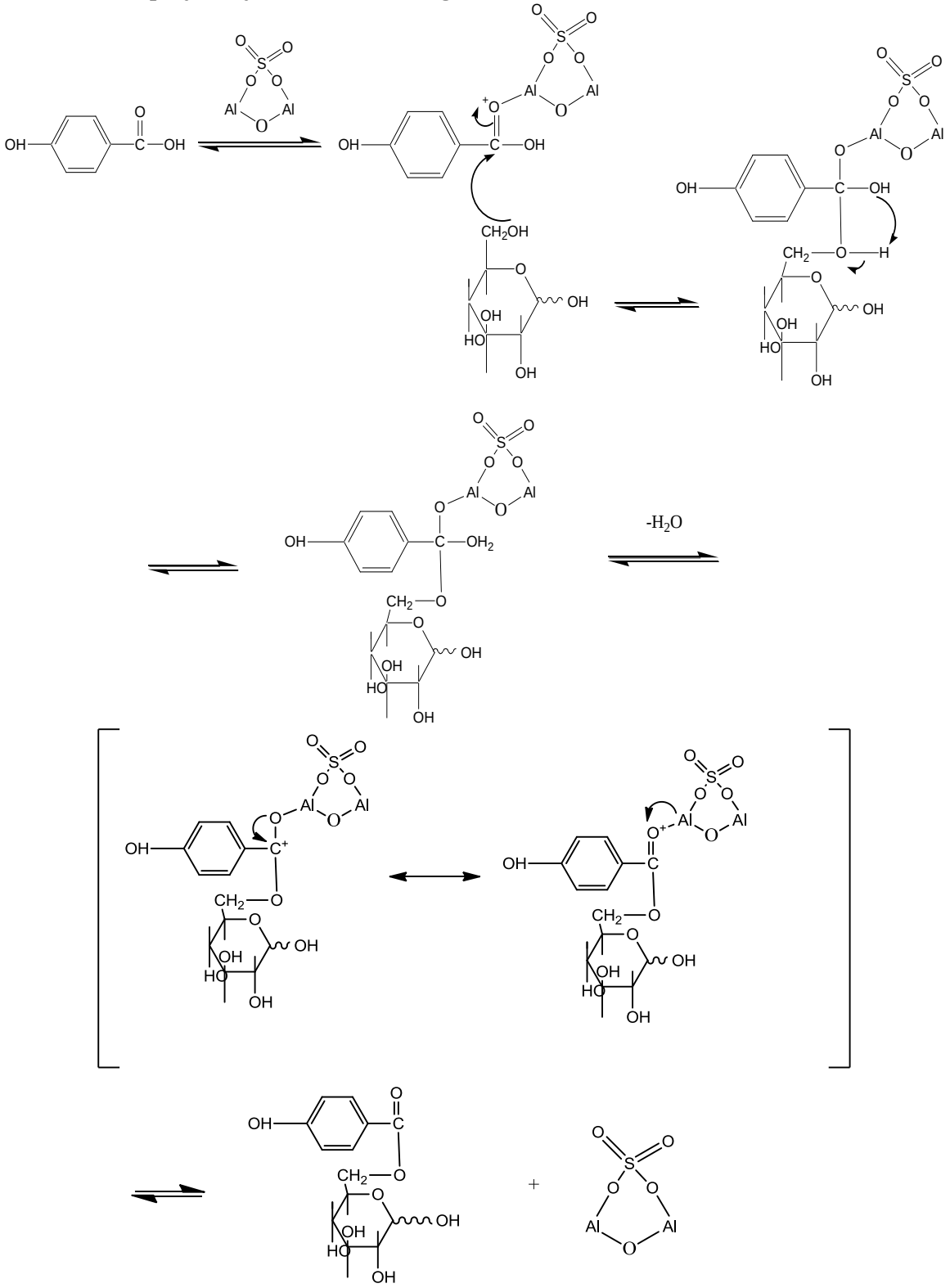

Figure 5. The mechanism of esterification of p-hydroxybenzoic acid with glucose using SO_4^{2-} Al_2O_3 catalyst

The esterification of p-hydroxybenzoic acid involved protonation and deprotonation (Figure 5). The carbonyl oxygen in p-hydroxybenzoic acid was protonated. The next step was nucleophilic glucose that attacked positive carbon. The removal of water generated the ester. Then, this water reacted with Al catalyst. Afterward, H^+ from the water was released. The reaction between water and $S0_4^{2-}/Al_2O_3$ catalyst is presented in Figure 6.

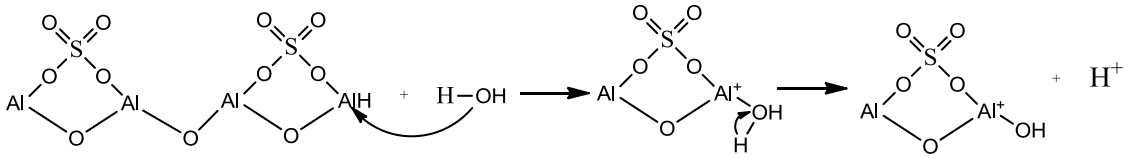

Figure 6. The reaction of water, the byproduct of esterification, with SO_4^{2-}/Al_2O_3 catalyst

Characterization of esterification products: FTIR, HPLC, LC-MS

The FTIR graphs of p-hydroxybenzoic acid and the produced esters are described in Figure 7 and Figure 8.

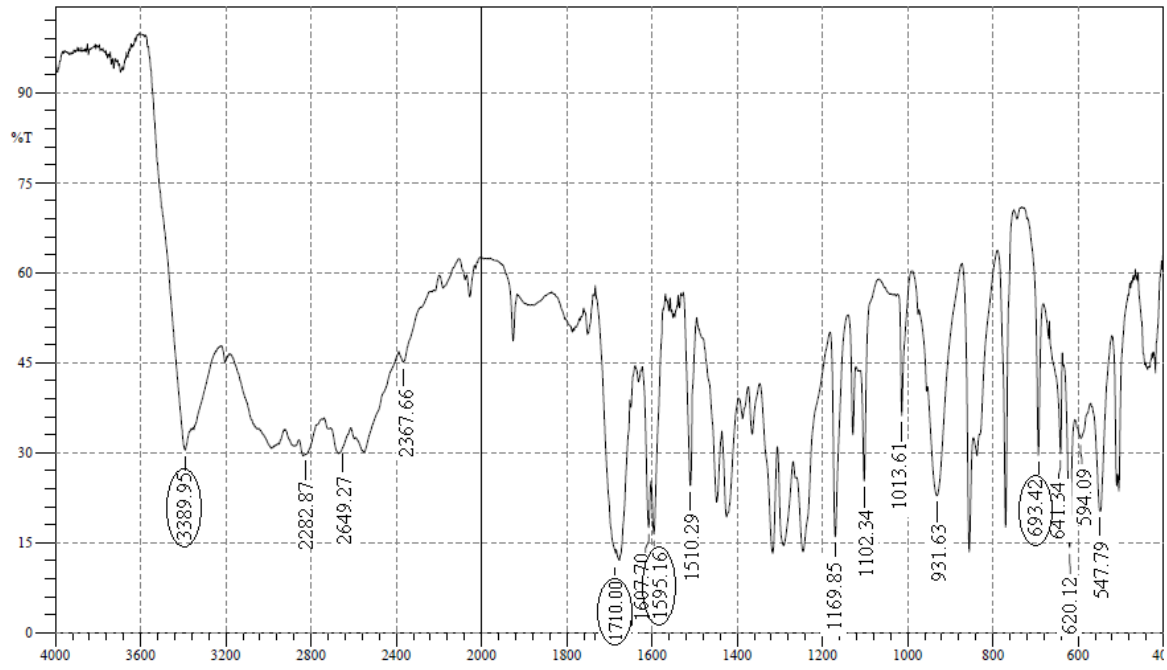

Figure 7. The FTIR graph of p-hydroxybenzoic acid

Table IV. Interpretation of the FTIR spectra of p-hydroxybenzoic acid by functional groups

Functional groups	**Wavenumbers of Detected Bands (cm^{-1})**	**Wavenumbers (cm^{-1})** (Sastrohamidjojo, **1992)**
Carboxyl C=O	1710.00	1725-1700
Phenolic O-H	3389.95	3400-2400
Aromatic out-of-plane C-H	900-690	900-690
Aromatic C=C	1595.16	1600-1475

The FTIR spectra of p-hydroxybenzoic acid are presented in Figure 7. The most intense absorbance band at 1710 cm^{-1} is within the wavenumber region of 1725-1700 cm^{-1} (Table IV) corresponding with the carboxyl C=O group. It means that p-hydroxybenzoic acid contains this functional group. Meanwhile, the band at 3389.95 cm^{-1} in the FTIR spectra is attributed to a phenolic hydroxyl group (O-H). Based on Figure 7, the FTIR graph shows vibrations of aromatic out-of-plane C-H appearing between 900 and 690 cm^{-1} and a peak on 1595.16 cm^{-1} that corresponds with the wavenumbers of aromatic C=C group. These bands indicate that p-hydroxybenzoic acid contains aromatic out-of-plane C-H and aromatic C=C.

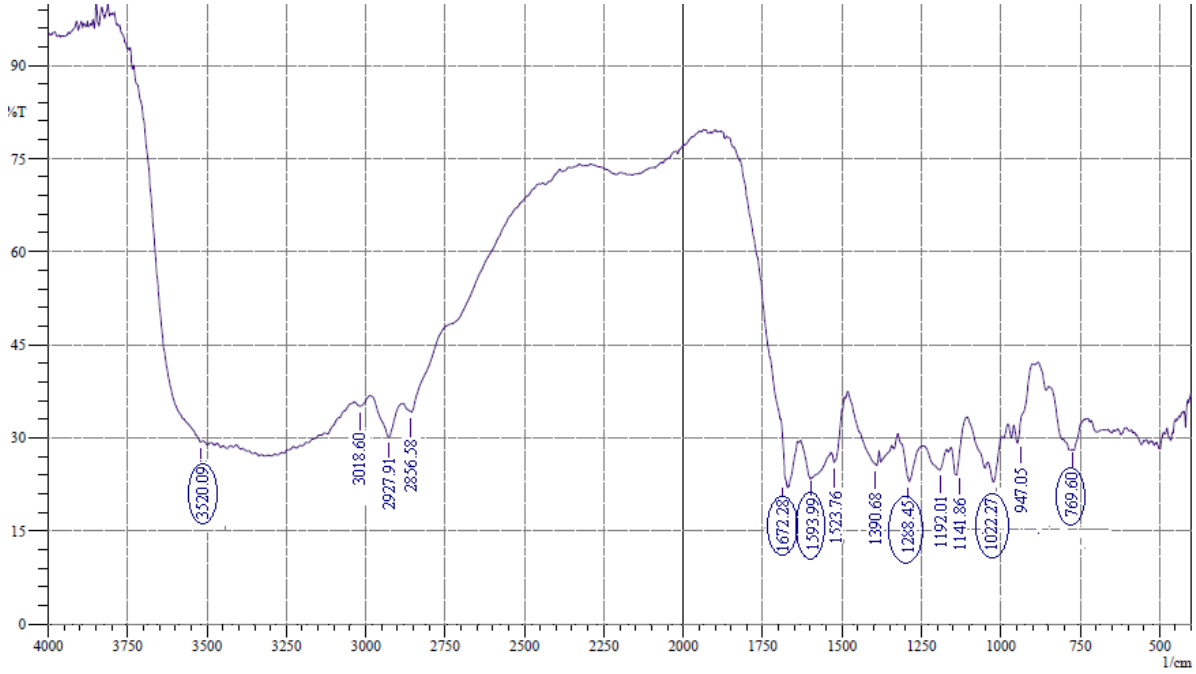

Figure 8. The FTIR graph of the esterification reaction

Table V. Interpretation of FTIR spectra of the esterification reaction by functional groups

Functional groups	Wavenumbers of Detected Bands (cm^{-1})	Wavenumbers (cm^{-1}) (Sastrohamidjojo, 1992)
Ester C=O	1672.28	1820-1660
Ester C-O	1288.45	1300-1000
Out-of-plane C-H	769.60	900-690
Aromatic C=C	1598.99	1600-1475
Alcohol O-H	3520.09	3600-3300
Alcohol C-O	1022.27	1300-1000

The FTIR spectra of the esterification reaction (Figure 8) show bands appearing in the region of 1820-1160 cm^{-1} that, referring to Table V, indicate the presence of ester C=O. The spectra also show several peaks at 1288.45 cm^{-1}, 1598.99 cm^{-1}, 3520.09 cm^{-1}, and 1022.27 cm^{-1}, which correspond with the wavenumber regions unique to ester C-O, aromatic C=C, alcohol O-H, and alcohol C-O, respectively. There is also a band attributed to the molecular vibrations of out-of-plane C-H in the esterification reaction, i.e., at 769.60 cm^{-1}.

HPLC analysis of esterification reaction

Figures 9 and 10 depict the alternating increase and decrease in the % yield and % conversion of the esterification of p-hydroxybenzoic acid with glucose using 3% and 5% SO_4^{2-}/Al_2O_3 catalysts. The % yield of the esterification using 3% SO_4^{2-}/Al_2O_3 catalyst increases and decreases slightly during 18 hours of reaction time before it rises sharply at Hour 24 (Figure 9). Meanwhile, the % conversion climbs dramatically during one-sixth of the reaction time (i.e., Hour 4) but later drops at Hour 6 and rises sharply at the end of the reaction time. As for the esterification using 5% SO_4^{2-}/Al_2O_3 catalyst, the % yield fluctuates steadily throughout the 24-hour reaction time, but the % conversion shows a steep decline after one-sixth and half of the reaction time (Hour 4 and 12).

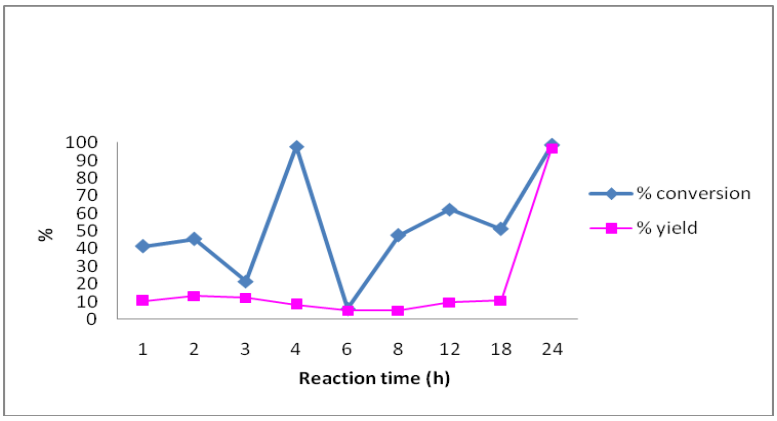

Figure 9. The yield and conversion from the esterification of p-hydroxybenzoic acid with glucose using 3% SO_4^{2-}/Al_2O_3 catalyst

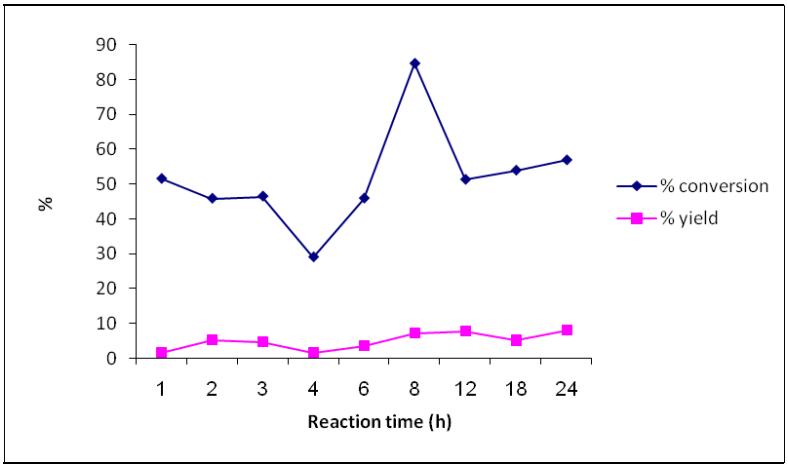

Figure 10. The yield and conversion from the esterification of p-hydroxybenzoic acid with glucose using 5% SO_4^{2-}/Al_2O_3 catalyst

The LC-MS analysis of the produced esters

Based on the results of the LC-MS analysis, the high intensity appeared at a retention time of 1.7 minutes. The molecular weights of the generated esters in this study are 307.12 (Figure 11) and 537.58 (Figure 12). The molecular structure of the product depicted in Figure 11 has one p-hydroxybenzoic acid that binds with glucose because the real molecular weight is 300. Meanwhile, the

one presented in Figure 12 has three p-hydroxybenzoic acids binding with glucose because the real molecular weight is 540.

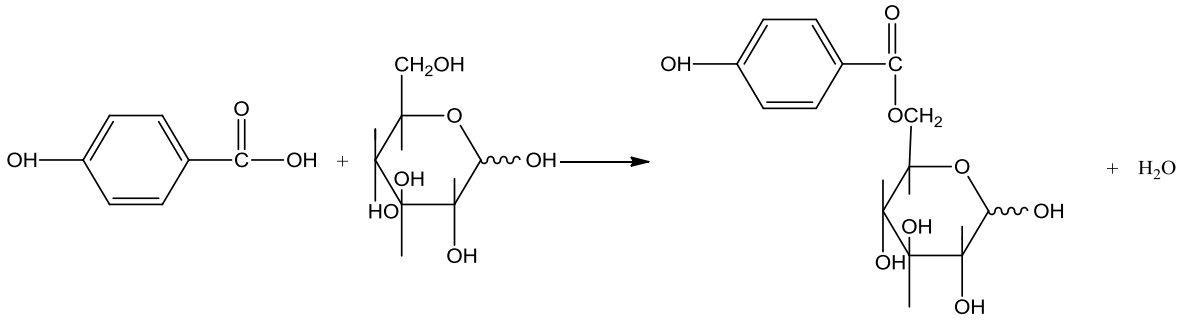

Figure 11. Products comprising one p-hydroxybenzoic acid with glucose

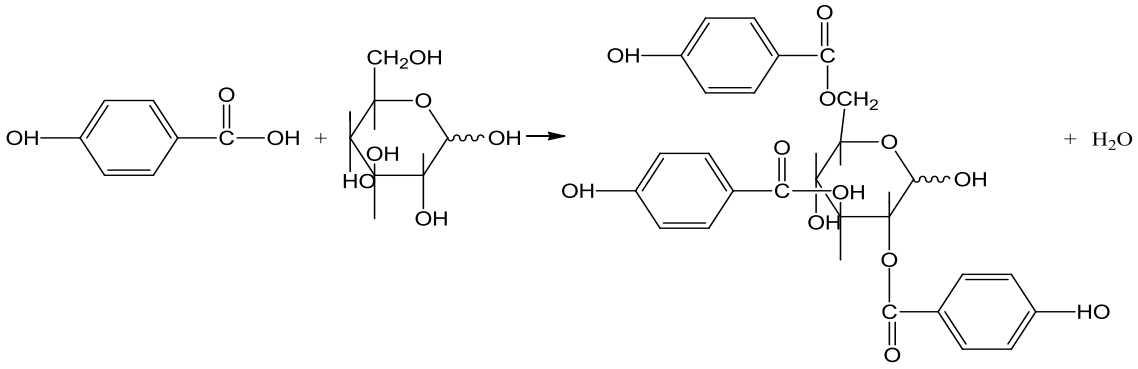

Figure 12. Products containing three p-hydroxybenzoic acids with glucose

CONCLUSION

The esterification reaction of p-hydroxybenzoic acid with glucose in this research used 3% and 5% SO_4^{2-}/Al_2O_3 catalysts. The % yield is high after 24 hours of reaction time using both catalysts, while the % conversion fluctuates during the reaction. Based on the LC-MS analysis results, the esterification products comprise one p-hydroxybenzoic acid and three p-hydroxybenzoic acids binding with glucose, and their molecular weights are 300 and 540, respectively.

REFERENCES

Alvarez, M., Ortiz, M. J., Ropero, J. L., Nino, M. E., Rayon, R., Tzompantzi, F. and Gomez, R, 2009. Evaluation of Sulfated aluminas synthesized via the sol-gel method in the esterification of oleic acid with ethanol, *Chem.Eng.Comm*, 196(10)(February 2010): 1152–1162.

Fessenden, R. J. and Fessenden, J. S, 1989. *Kimia Organik Jilid 2*. 3rd ed. Jakarta: Erlangga.

Kiss, A. A., Dimian, A. C. and Rothenberg, G, 2008. Biodiesel by catalytic reactive distillation powered by metal oxides, *Energy &Fuels*, 22: 598–604.

Lo, D. E., Suwannakarn, K., Goodwin, J. G., Bruce, D. A. and Carolina, S, 2008. Reaction kinetics and mechanism for the gas- and liquid-phase esterification of acetic acid with methanol on tungstated zirconia, *Ind.Eng.Chem.Res*, 47(7)(2008): 2221–2230.

Miranda, B. C., Chimentão, R. J., Santos, J. B. O., Gispert-guirado, F., Llorca, J., Medina, F., Bonillo, F. L. and Sueiras, J. E, 2014.Conversion of glycerol over 10 % Ni/γ-Al_2O_3 catalyst, *Applied Catalysis B: Environmental*. Elsevier B.V., 147: 464–480.

Prasitturattanachai, W. and Nuithitikul, K, 2013. esterification of free fatty acids in crude palm oil

using alumina-doped sulfated tin oxide as a catalyst, *International Journal of Chemical and Molecular Engineering*, 7(7): 821–825.

Pudi, S. M., Mondal, T., Biswas, P., Biswas, S. and Sinha, S, 2014.conversion of glycerol into value-added products over cu-ni catalyst supported on γ-Al_2O_3 and activated carbon, *International Journal of Chemical Reactor Engineering*, 12(1): 1–12.

Ramli, A. and Farooq, M, 2015. Optimization of process parameters for the production of biodiesel from waste cooking oil in the presence of bifunctional □-Al_2O_3 -CeO_2 supported catalysts, *Malaysian Journal of Analytical Sciences*, 19(1): 8–19. Available at: http://www.ukm.my/mjas/v19_n1/pdf/Anita_19_1_2.pdf.

Rane, S. A, 2016. Esterification of glycerol with acetic acid over highly active and stable alumina-based catalysts: a reaction kinetics study, *Chemical and Biochemical Engineering Quarterly Journal*, 30(1): 33–45.

Sastrohamidjojo, H. (1992) *Spektroskopi Inframerah*. 1st edn. Edited by Sardjoko. Yogyakarta: Liberty.

Sastrohamidjojo, H, 2013. *Dasar-dasar spektroskopi*. Yogyakarta: Universitas Gadjah Mada Press. Available at: http://ugmpress.ugm.ac.id/id/product/kimia/dasar-dasar-spektroskopi.

Su, X., Li, J., Xiao, F., Wei, W. and Sun, Y, 2009. Esterification of salicylic acid with dimethyl carbonate over mesoporous aluminosilicate, *Ind.Eng.Chem.Res*, 48: 3685–3691.

Suwannakarn, K., Lotero, E. and Goodwin, J. G, 2007. Solid Brønsted Acid Catalysis in the Gas-Phase Esterification of Acetic Acid, *Ind.Eng.Chem.Res*, 46: 7050–7056.

Yu, G. X., Zhou, X. L., Li, C. L., Chen, L. F. and Wang, J. A, 2009. Esterification over rare earth oxide and alumina promoted SO_4^{2-}/ZrO_2, 148: 169–173.

Zhang, L., Zhang, H.-T., Ying, W.-Y. and Fang, D.-Y, 2011. Intrinsic kinetic of methanol dehydration over Al_2O_3 Catalyst, *World Academy of Science, Engineering and technology*, 5(11):1538–1543.